Int J Life Cycle Assess (2011) 16:859–868
DOI 10.1007/s11367-011-0323-5

LCA FOR WOOD

A life cycle assessment case study for walnut tree (*Juglans regia* L.) seedlings production

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Received: 23 March 2011 / Accepted: 7 July 2011 / Published online: 22 July 2011

Abstract
Purpose High-quality wood production is based on both natural forestry populations and dedicated tree plantations, also mentioned as industrial plantations. The establishment of dedicated plantations needs high-quality seedlings, often grown in a nursery, having specific genetic and morphological features. From seed gathering to final selling, the growth of the seedlings needs human interventions and specific inputs such as fertilizers, pesticides, substrates, and capital goods (e.g., pots and greenhouses). All these inputs of course can cause not negligible environmental impacts, due to their production, maintenance, and final disposal. For these reasons, the environmental impact due to seedlings production in a nursery deserves deep analysis to assess the overall impact linked to wood supply chain: it is important that wood products are able to meet high environmental standards. This study is focused on 1- and 2-year-old walnut tree (*Juglans regia* L.) seedlings, aimed to high-quality timber production.
Materials and methods Life cycle assessment (LCA) methodology was adopted according to ISO 14040 standards. As case study, a nursery located in the South of Italy was studied. Both 1- and 2-year-old seedlings were analyzed from the LCA point of view and then compared, adopting 100 seedlings as functional unit.
Results and discussion Three inputs, plastic production, forming, and disposal to landfill, can be identified as the greatest polluters for both 1- and 2-year-old seedlings; for all the impact categories taken into account, their emissions joined always exceeded the 50% of the total amount, reaching values up to 90% (e.g., abiotic depletion, fresh water aquatic ecotoxicity, and photochemical oxidation). Two-year-old production system needs more inputs than 1-year-old; therefore, its greatest environmental impact was expected, but it is interesting to stress the increasing registered over the second year of growing, which reaches values up to 747% (fresh water aquatic ecotoxicity), most of which is due to polypropylene (mulching cloth, trays, and first of all, the pots).
Conclusions For four out of ten impact categories, polypropylene caused the greatest impact; therefore, interventions in this phase of the production system could be useful to reduce the overall environmental impact. Further investigations regarding the mortality rate for 1- and 2-year-old seedlings (after the plantation) are needed to better compare practical, economic, and environmental aspects.

Keywords Industrial plantations · *Juglans regia* · LCA · Life cycle assessment · Timber · Wood

1 Introduction

Wood is considered as the world's most important renewable material and regenerative fuel. Its main applications are construction material for housing and civil engineering, furniture, poles, and reinforcement for mining. Over the past 30 years, international trade in forest products has increased roughly threefold in terms of value, and now accounts for about 3% of total world trade (Mattew 2000).

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Increasing demand for commercial timber and other wood and paper products has encouraged many countries to expand the area devoted to forest plantations. The major challenge for policy-makers all over Europe will be to satisfy the increasing demands placed on forests to produce a wider range of goods and services for society (FAO 2004). The European furniture sector comprises around 150.000 companies, generates a turnover of almost 126 billion € and an added value of 38 billion € and employs around 1.4 million people (Eurostat 2006). The main producers are Italy and Germany followed by UK, France, and Spain. Despite Italy is one of the most important exporters of furniture in Europe, at the same time is a great importer of foreign timber. It is worth to mention that beside spontaneous forestry stands, timber production is also based on dedicated tree plantations (also mentioned as industrial plantations), often established in rural areas, which need considerable human interventions for their establishment and management. The need for further exploitation of natural forests could be greatly reduced by expanding wood production from industrial wood plantations. In Italy, walnut tree (*Juglans regia* L.) may be considered as one of the most valuable among the indigenous species used for artificial plantations aimed to high-quality timber production (Minotta 1981).

According to Kyoto Protocol, Italy agrees to reduce collective greenhouse gas emissions by 6.5% from 1990 level. Forestation and tree plantations aimed to high-quality timber production are taken into account by Kyoto Protocol for CO_2 subtraction from atmosphere; therefore, their environmental role cannot be neglected (Magnani et al. 2005).

In Italy, about 50% of the total plantations funded by public funds involved precious timbers such as cherry, chestnut, ash, and first of all, walnut tree (Falleri and Giannini 1994), which, better than other species, is well adapted to Italian climate and soil, showing interesting growing rate (Di Vaio and Minotta 2005; Alberti et al. 2006; Cutini and Giannini 2009; Tani et al. 2006). According to Giannini and Mercurio (1997), walnut tree alone covers 6.500 ha in Italy, thanks to the timber's technological and aesthetics quality.

Dedicated tree plantations are placed just in the middle of a complex process aimed to high-quality timber production. Both downstream and upstream are placed production systems such as seedlings grown in the nurseries, forestry operations (e.g., felling, bucking, etc.), transportation to sawmills, without mentioning the industrial processes aimed to wooden goods production (e.g., furniture). The establishment of walnut tree plantations aimed to high-quality timber production, needs high-quality seedlings, grown in a nursery, having specific genetic end morphological requisites. From seed gathering to final selling, potentially pollutant inputs such as fertilizers, pesticides, capital goods (buildings, greenhouses, etc.) may be part of the production system. All the above-mentioned processes may be source of environmental impacts which have to be assessed if we consider that to ensure access to an environmentally concerned market, it is important that wood products are able to meet high environmental standards.

This study analyzes the production of 1- and 2-year-old walnut tree seedlings in a nursery, aimed to the establishment of tree plantations for high-quality timber production. The results from both the production systems were assessed and compared in order to point out the relative environmental impacts and the so-called hot spots.

2 Methodology

2.1 Description of the system

As case study, a production system adopted in a nursery located in the Region of Basilicata (Potenza), in the South of Italy, was analyzed. Both 1- and 2-year-old seedlings have been studied and compared from the LCA point of view (ISO 14040 2006). The production systems are described and deeply analyzed in Fig. 1.

2.1.1 Seed gathering

The gathering of the nuts is the very first step of the production system under study. The importance of the seed is universally acknowledged (Gradi 1994): the seed selection is a very delicate step indeed, from which the evolution of the plants depends. The nuts should be gathered from trees that grow in climatic conditions similar to those where the nursery is located. The origin of the plants still has its importance since every locality has cultivar suited to that specific climate (Bernetti 1995); moreover the genetic origin influences the shape of the trunk and therefore the value of the timber (Paris et al. 2005).

In Italy, the seeds of walnut tree are gathered between September and October, preferably on the tree, beating the branches by means of a pole or using mechanical shakers. Subsequently, the husk is removed (manually or mechanically), the nuts are cleaned by immersion in water, and those who float are discarded because they were empty. Then, they are dried in a cool and well-ventilated place, in order to reach final moisture content by 15%. The seeds of this species have a very high purity (100%), vitality (84%), and germinability (usually 80%) which can even reach 90% (Giannini and Mercurio 1997).

According to Falleri (1994), even if the nuts are classified as orthodox seeds, they are better stored if a high water content is preserved; on the contrary, according to

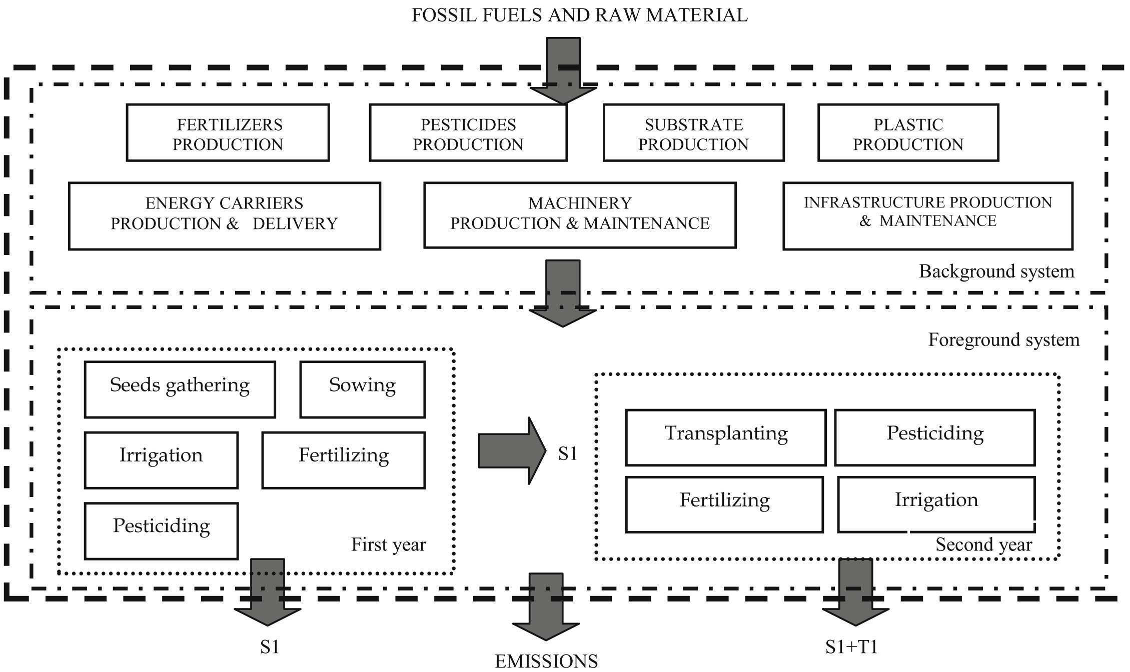

Fig. 1 System boundaries for 1- (S1) and 2-year-old (S1+T1) seedlings. At the end of the first year, S1 may go out the system and commercialized, or may be transplanted into individual pots where they grow over the second year. In this last case, they get out the system as S1+T1

Bernetti (2005), they are classified as recalcitrant seeds. A broadly adopted preservation method consists on storing the seeds into a container filled with sand and peat for a few months (12–20 weeks), with the temperature ranging from 3°C to 5°C.

In our case study, the nuts are gathered once a year from a natural walnut tree population (Fossa Cupa Regional wood) located in the municipality of Abriola (Potenza), 10 km far from the nursery. Roughly 200 kg of seeds are collected in jute sacks and then transported to the nursery by means of a pick-up. Roughly 14.000 nuts are sown every year, from which roughly 10.000 seedlings are awaited at the end of the second year. Such a reduction is due to germination percentage lower than 100%, pathogens, animals who eat the seeds, unhealthy or malformed seedlings that cannot be commercialized. Jute sacks were not considered because they were used for the gathering of others species' seed. The nuts are cleaned manually by using water and then stored for a few months into a plastic container placed in a dry ambient (refrigerated rooms are not strictly necessary). This last step was not considered because the seeds are placed into a big room shared with several species which do not require any refrigeration systems; moreover, the room itself that is part of a big building, is used during several phases for other productive cycles. Energetic consumptions (e.g., electricity) due to the storage, was not taken into account because not strictly required for nuts preservation.

2.1.2 Sowing and growing

Modern nurseries can grow walnut tree seedlings by sowing the seeds into seedling trays, filled with a specific substrate (often pumice and peat) where they grow for 1 year (S1) and then may be transplanted into plastic pots where they grow over the second year (S1+T1). From the practical point of view, both 1- and 2-year-old seedlings may be commercialized and adopted to establish a tree plantation aimed to high-quality timber production. S1 are preferred because cheaper than S1+T1, but on the other side, S1+T1 are stronger than S1. S1+T1 can be grown if the nursery is well organized and modern capital goods are available (Gradi 1994), as in our case.

For what concerns our study, two different areas were defined: in the first one, the seeds are sown into multiple containers (seedling trays), where the seedlings grow over the first year and then are transplanted into individual pots and moved to another area of the nursery where they grow over the second year (1- and 2-year-old seedlings are from now on mentioned as S1 and S1+T1, respectively). The nuts are sown into cell trays made of polypropylene (PP) and expanded polystyrene (EPS) which are placed on metallic bars (made of coated iron) to avoid the direct contact with the soil. At the beginning of the second growing season, S1 are manually transplanted into bigger and individual pots made of PP, placed for practical reasons on plastic grids made of PP, and then moved to another area

of the nursery by means of metallic trolleys. This step is performed manually and therefore not considered in our study. Roughly 10.000 S1+T1 are obtained at the end of the second growing season and then commercialized. According to the interviews, a mortality rate by 15% hits the seedling over the first and the second year. To protect the nuts against the animals, the trays are covered with a cloth made of polyester (PET). To avoid the growing of weeds below the trays and pots, a mulching cloth made of PP is used to cover the soil. A mix of pumice and peat (10% and 90%, respectively), is used as substrate. As bulk density, 700 and 650 kg/m^3 were used for peat and pumice, respectively. Two different kinds of fertilizers, containing N, P, and K are manually added to the substrate every year. For what concerns the irrigation, the water comes from a big pool located on a little hill just beside the nursery. Energy is not required, neither for water collection nor for irrigation, since the water from the spring is collected into the pool and then flows toward the nursery, thanks to the gravity. A plastic pipe network conducts the water to the nursery, where it is used to irrigate the plants. In our case study, the amount of plastic of which are made the tubes that surrounds the trays and pots where the seedlings are grown, was computed. The main hydraulic network was excluded because it conducts the water towards thousands of plants of different species that grow in the nursery. Pesticides are applied yearly, once or twice a year, depending on the needs. In our case study, two yearly applications were considered for precautionary reasons. Treatments are performed by means of a tractor equipped with a tank containing the pesticides. The tractor itself was excluded because it is used to treat several species at once; moreover, it is used just for a very short time. To protect the plants against the direct sunlight and the hail, the seedlings are placed under a protective structure made of steel and reinforced concrete, equipped with a shade cloth made of HDPE. For our purposes, only the shade cloth was included into the inventory; the metallic structure was not computed because his life span is more than 20 years.

As final scenario for all the plastic goods used in this case study, a landfill was hypothesized. Transportation to the nursery of goods such as pots, trays, pesticides, fertilizers, and the component of the irrigation system, was also excluded because of lack of data. The transportation to the landfill of the plastic residues at the end of their life span (irrigation system, nursery trays, etc.), performed by lorry, was instead added. Since packaging is not always necessary because it depends on the distance of transportation and the number of plants delivered, this phase was not considered. Table 1 shows the life span of the inputs that enter the production system, according to the interviews.

Table 1 Inputs and life span

Input	Life span (years)
Tray	5
Pot	1
Grid	5
Metallic bar	>20
Covering cloth	1
Mulching cloth	10
Substrate	1
Main pipe[a]	10
Conjunction pipe[a]	10
Micro-pipe[a]	5
Steel bars[a]	>20
Butterfly valve[a]	5
Closure valve[a]	5
Shade cloth	5
Shading structure (steel and concrete)	>20
Metallic trolley	>20

[a] Irrigations system

2.2 Functional unit

The function of the system under study is the growing of walnut tree (*J. regia* L.) seedlings, aimed to high-quality timber production. One- and 2-year-old seedlings were considered; the first year, they grow into multiple containers and then they are transplanted into individual plastic pots. As functional unit, 100 seedlings were chosen; a numerical functional unit was then adopted according to bibliography (Russo and De Lucia Zeller 2007; Aldentun 2002).

3 Data quality

Data were gathered by means of company reports, interviews, informal conversations and completed with bibliographic resources when necessary. The inventory was compiled adopting 20 years as life span, according to bibliography (Russo et al. 2006); therefore, the capital goods having a life span greater than 20 years were excluded. The environmental impact due to the production and maintenance of capital goods can be neglected, taking into account their long life span (González-García et al. 2009). Site-specific data regarding energy and commodities were used together with data collected in relevant databases and literature. The transportation phase regarding the seedlings (from the nursery to the hypothetic plantation), the pesticides, fertilizers, pots, and the components of the irrigation system (from the productions site to the nursery) was excluded. Secondary data (Table 2) were gathered from

Table 2 Secondary data sources

Input	Source
HDPE–PP–EPS–PET	Hischier (2007)
	IDEMAT (2001)
	LCA Food DK (2010)
Plastic processing	Hischier (2007)
Steel	Classen et al. (2009)
Fertilizers	LCA Food DK (2010)
	Nemecek et al. (2007)
Pesticides	Althaus et al. (2007)
	Nemecek et al. (2007)
Peat	Dones et al. (2007)
Pumice	Kellenberger et al. (2007)
Transport	Spielmann et al. (2007)

bibliography (e.g., active ingredient of the chemicals, characteristics of the fertilizers, etc.). For what concerns the mulching cloth, only data regarding EPS production were considered: the assembly itself of the cloth was excluded because of the lacking of data. All the plastic goods used in the production process and included in the inventory, are assumed to be transported and disposed off in a landfill as final scenario. The relative emissions were collected from Doka (2009) and Spielmann et al. (2007).

NH_3, N_2, and N_2O emissions to air, due to fertilizer application, have been assessed according to Antòn and Baldasano (2004), Brentrup et al. (2000), Audsley et al. (1997). The assimilation of CO_2 into the seedlings' biomass was not considered because of lack of data. Since the plants grow for 1 or 2 years into plastic pots and the ground is covered with a mulching cloth under which a layer of gravel was placed to avoid the growth of weeds, NO_3^- leaching was not considered.

The resources needed to feed and clothe the people involved in the specified work processes, and the manpower was excluded from the system boundaries. Table 3 shows the date that are part of the inventory, for both 1- and 2-year-old seedlings.

4 Results

According to CML 2 baseline 2000 V2.04 (Guinée et al. 2001), abiotic depletion (AD), acidification (AC), eutrophication (EP), global warming (GW), ozone layer depletion (OLD) human toxicity (HT), fresh water aquatic ecotoxicity (FE), marine aquatic ecotoxicity (ME), terrestrial ecotoxicity (TE), and photochemical oxidation (PO) were adopted as impact categories. LCA software SimaPro 7.2 developed by PRé Consultant (2010) was adopted for impact assessment. Characterization was carried out and the results are showed below. For practical reasons for each impact category, the results are divided into eight inventory categories (see Tables 4, 5, and 6), depending on the nature of the input.

4.1 One-year-old seedlings

Abiotic depletion (AD) The impact due to the production of the plastic goods caused the 78.2% of the total result: in particular, PP and EPS play a key role, representing the 43.6% (1.59E-02 Sb eq) and the 26.4% (9.60E-03 Sb eq), respectively, followed by thermoforming which represents the 8% (2.91E-03 kg Sb eq).

Acidification (AC) Substances such as sulfur oxide (1.80E-03 kg SO_2 eq), sulfur dioxide (8.80E-03 kg SO_2), and nitrogen oxide (3.90E-03 kg SO_2 eq) to air are emitted in this category, most of which are from plastic production. As well as for the previous impact category, plastic production is the major polluter (61.8%): PET, PP, and EPS emit 3.92E-03, 3.04E-03, and 2.61E-03 kg SO_2 eq, respectively, which represent the 25%, 19.3%, and 16.6% of the total emissions. It is also worth mentioning that the contributions due to forming (10.5%) and peat (8.4%), emitting 1.65E-03 and 1.31E-03 kg SO_2 eq, respectively.

Eutrophication (EP) Nitrogen oxide (1.00E-03 kg PO_4^{3-} eq) and ammonia (2.00E-04 PO_4^{3-} eq) to air, phosphate (2.60E-03 kg PO_4^{3-} eq), COD (3.00E-03 PO_4^{3-} eq), and ammonium ions (6.30E-03 PO_4^{3-} eq) to water, are mostly due to final disposal, the greatest emitter in this category (46.6%). It is also worth mentioning the impact due to forming (17.4%), in particular, thermoforming which emits 9.64E-04 kg PO_4^{3-} eq. The impact due to plastic (12.6%) and peat (10.6%) is also not negligible, the last one of which emits 8.14E-04 kg PO_4^{3-} eq.

Global warming (GW) This category refers to greenhouse gasses such as carbon dioxide and methane, which are emitted to air (2.90E+00 kg and 5.00E-01 kg CO_2 eq, respectively). As a whole, the 53.9% of the total emissions in this impact category comes from plastic production: PP and EPS are the greatest contributors, emitting 9.60E-01 (23.6%) and 7.97E-01 kg CO_2 eq (19.6%), respectively. Also, diffuse emissions from fertilizers application (13.1%) and forming (13.7%) does not have a negligible impact.

Ozone layer depletion (OLD) Halon 1211 and 1301 emissions to air, are greatly involved in this category (1.82E-08 and 4.32E-08 kg CFC-11 eq, respectively), mostly due to foaming ad transport. Once again, plastic forming has the greatest impact (42.1%): thermoforming alone emits 1.87E-08 kg CFC-11 eq which represents the

Table 3 Inventory

Type	Unit	1-year-old seedlings (S1)	2-year-old seedlings (S1+T1
		Input from technosphere	
HDPE	kg	0.022	0.19
EPS	kg	0.24	0.24
PET	kg	0.02	0.02
PP	kg	0.49	6.6
Pumice	kg	2.1	10
Peat	kg	20.7	94.9
N	kg	0.02	1
P_2O_5	kg	0.01	0.6
K_2O	kg	0.08	0.4
Generic fertilizer	kg	0.03	0.1
Carbamante-compounds	g	1.8	4.8
Pyridine-compounds	g	0.7	1.9
Pyretroid-compounds	g	0.5	1.2
		Output to technosphere	
Seedlings	Unit	100	100
		Output to environment	
NH_3 (air)	g	0.4	2
N_2O (air)	g	0.2	1
N_2 (air)	g	2	9

21.9% of total emissions. For the first time, transport causes a relatively high amount of emissions (14.9%): transportation of the seeds emits 1.07E-08 kg CFC-11 eq, which represent the 12.6% of the total. Substrate, in particular, peat, emits 1.39E-08 kg CFC-11 which represents the 16.5% of the total. Also, the emissions from the pesticides play a relatively important role, representing the 12.0% of the total emissions.

Human toxicity (HT) Several toxic elements are connected with this category: vanadium, selenium, and barium emissions to water (2.04E-01, 1.4E-01, and 1.0E-01 kq 1.4-DB eq, respectively), are mostly due to plastic production and final disposal. The total impact due to disposal, forming, substrate and plastic production, causes the 93.8% of the total emissions in this impact category (39.3%, 26.9%, 15.4%, and 12.2%, respectively). In particular, thermoforming and peat emit 1.91E-01 and 1.54E-01 kg 1.4-DB eq, representing the 19% and 15.3%, respectively.

Fresh water aquatic ecotoxicity (FE) Vanadium, copper, nickel, and cobalt (5.8E-01, 2.9E-01, 2.3E-01, and 1.2E-01 kg 1.4-DB eq, respectively) are emitted to water, most of which are from final disposal, which caused the 72.3% of the total emissions in this category. Peat and thermoforming have a relevant role too in this category, emitting 1.30E-01 and 1.66E-01 kg 1.4-DB eq, respectively.

Marine aquatic ecotoxicity (ME) Beryllium and vanadium, most of which due to plastic production and disposal, are emitted to water (6.5E+02 and 5.5E+02 kg 1.4-DB eq,

Table 4 Inventory categories: depending on the nature of the input that enters the system, eight inventory categories are used to distinguish different kinds of emissions

Inventory category	Description
Diffuse emissions	Emissions to air due to the application of fertilizers.
Transportation	Seeds transportation (from the site where they are collected to the nursery) and waste transportation to the landfill.
Plastic	Production of the plastic goods used in the nursery (pots, trays, irrigation system etc.).
Substrate	Peat and pumice production.
Fertilizers	Fertilizers production.
Forming	Industrial processes which involve the forming of the plastic goods included in the inventory.
Pesticides	Pesticides production.
Disposal	Emissions from the landfill: all the plastic elements included in the inventory are disposed off in a landfill.

Table 5 Characterization: impact categories and results for 1-year-old seedlings (S1)

Impact category	Unit	Total	Diffuse emissions	Transport	Plastic	Substrate	Fertilizers	Forming	Pesticides	Disposal
AD	kg Sb eq	3.64E-02	0.00E+00	6.09E-04	2.85E-02	1.89E-03	9.06E-04	4.12E-03	2.86E-04	1.02E-04
AC	kg SO_2 eq	1.57E-02	6.40E-04	3.47E-04	9.72E-03	1.32E-03	9.36E-04	2.55E-03	1.48E-04	5.58E-05
EP	kg PO_4^{3-} eq	7.69E-03	1.40E-04	1.09E-04	9.62E-04	8.19E-04	6.37E-04	1.34E-03	9.18E-05	3.59E-03
GW	kg CO_2 eq	4.07E+00	5.92E-02	8.95E-02	2.19E+00	3.67E-01	2.32E-01	5.56E-01	3.32E-02	6.36E-02
OLD	kg CFC-11 eq	8.53E-08	0.00E+00	1.27E-08	9.90E-09	1.41E-08	1.18E-10	3.59E-08	1.02E-08	2.32E-09
HT	kg 1.4-DB eq	1.00E+00	4.00E-05	3.97E-02	1.22E-01	1.55E-01	1.71E-03	2.70E-01	2.15E-02	3.95E-01
FE	kg 1.4-DB eq	1.51E+00	0.00E+00	1.43E-02	3.59E-02	1.31E-01	8.03E-04	2.27E-01	1.13E-02	1.09E+00
ME	kg 1.4-DB eq	1.87E+03	0.00E+00	3.04E+01	3.40E+01	2.80E+02	6.69E-01	4.78E+02	2.15E+01	1.02E+03
TE	kg 1.4-DB eq	4.87E-03	0.00E+00	2.63E-04	3.04E-04	7.57E-04	6.99E-06	2.74E-03	2.14E-04	5.84E-04
PO	kg C_2H_4	2.22E-03	0.00E+00	3.07E-05	5.26E-04	7.98E-05	2.48E-05	1.53E-03	1.31E-05	1.30E-05

respectively). As well as for the abovementioned impact categories, plastic disposal is the greatest emitter (54.7% of the total). Also worth mentioning, thermoforming and peat emitting 3.41E+02 and 2.79E+02 kg 1.4-DB eq, respectively.

Terrestrial ecotoxicity (TE) Vanadium to air (1.4E-03 kg 1.4-DB eq), chromium VI to soil (1.0E-03 kg 1.4-DB eq), and mercury to air (1.0E-03 kg 1.4-DB eq) are emitted in this category, due to foaming and thermoforming.

Thermoforming has a relevant role in this impact categories, emitting 1.68E-03 kg 1.4-DB eq (34.5%) followed by peat production which emits 7.51E-04 kg 1.4-DB eq (15.4%).

Photo oxidation (PO) Pentane, a blowing agent used in the production of polystyrene foam, is emitted to air (1.4E-03 kg C_2H_4 eq): up to 90% of these emissions are due to foaming, which alone counts more than half the total emissions (69%). In particular, polystyrene forming emits 1.46E-03 kg C_2H_4 eq, which represent the 65.8% of the total. It is also worth mentioning the contribution due to PP, EPS, and PET production, which emit 2.06E-04 (9.3%), 1.57E-04 (7.1%), and 1.48E-04 (6.7%)kg C_2H_4 eq.

4.2 Two-year-old seedlings

Abiotic depletion (AD) Plastic production counts for the 80.3% of the total amount in this impact category: propylene alone reaches the 73.8%, which means 2.04E-01 kg Sb eq. Also, thermoforming is an important contributor, representing the 13.5% (3.74E kg Sb eq).

Acidification (AC) Sulfur oxide (5.70E-02 kg SO_2 eq), nitrogen oxide (2.10E-02 kg SO_2 eq), and ammonia (4.6E-03 kg SO_2 eq) are emitted to air, most of which are from thermoforming and plastic production. As well as for the previous impact category, plastic production, and forming are the major emitters (55.5% and 26.6%, respectively). In particular, polypropylene and thermoforming emits 3.91E-02 and 2.12E-02 kg SO_2 eq, representing the 46.3% and 25.1%, respectively.

Table 6 Characterization: impact categories and results for 2-year-old seedlings (S1+T1)

Impact category	Unit	Total	Diffuse emissions	Transport	Plastic	Substrate	Fertilizers	Forming	Pesticides	Disposal
AD	kg Sb eq	2.77E-01	0.00E+00	8.60E-04	2.22E-01	3.91E-02	8.68E-03	4.30E-03	5.78E-04	9.08E-04
AC	kg SO_2 eq	8.44E-02	3.20E-03	5.20E-04	4.68E-02	2.24E-02	6.05E-03	4.57E-03	3.18E-04	4.99E-04
EP	kg PO_4^{3-} eq	5.71E-02	7.00E-04	1.49E-04	4.96E-03	1.29E-02	3.76E-03	2.31E-03	2.08E-04	3.21E-02
GW	kg CO_2 eq	2.29E+01	2.96E-01	1.29E-01	1.39E+01	5.14E+00	1.69E+00	1.14E+00	6.75E-02	5.68E-01
OLD	kg CFC-11 eq	4.01E-07	0.00E+00	1.85E-08	1.31E-08	2.62E-07	6.48E-08	3.92E-10	2.20E-08	2.08E-08
HT	kg 1.4-DB eq	7.42E+00	2.00E-04	4.80E-02	5.03E-01	2.58E+00	7.10E-01	7.80E-03	4.29E-02	3.53E+00
FE	kg 1.4-DB eq	1.28E+01	0.00E+00	1.54E-02	1.90E-01	2.23E+00	6.01E-01	2.69E-03	2.29E-02	9.77E+00
ME	kg 1.4-DB eq	1.52E+04	0.00E+00	3.40E+01	1.75E+02	4.59E+03	1.29E+03	2.23E+00	4.66E+01	9.11E+03
TE	kg 1.4-DB eq	3.35E-02	0.00E+00	2.94E-04	9.61E-04	2.31E-02	3.47E-03	2.46E-05	4.60E-04	5.22E-03
PO	kg C_2H_4	6.10E-03	0.00E+00	3.74E-05	3.08E-03	2.36E-03	3.66E-04	1.19E-04	2.73E-05	1.16E-04

Eutrophication (EP) Plastic production and final disposal emitted phosphate (1.70E-02 kg PO_4^{3-} eq) and COD (2.70E-02 PO_4^{3-} eq) to water.

Plastic disposal in the landfill is the greatest polluter, emitting the 56.2% of the total emissions in this impact category. Thermoforming as well is an important contributor, emitting 1.24E-02 kg PO_4^{3-} eq (21.7%), followed by PP (4.23E-03 kg PO_4^{3-} eq), and peat (3.73E-03 kg PO_4^{3-} eq).

Global warming (GW) Greenhouse gasses such as carbon dioxide (fossil) and methane (fossil) are emitted to air (1.78E+01 and 3.12E+00 kg CO_2 eq, respectively). Plastic production and forming, joined, reach the 83% of the total CO_2 eq emitted. As well as for the abovementioned impact categories, polypropylene production and relative thermoforming are the major emitters, causing the 53.8% and 21.4% of the total emissions, which means 1.23E+01 and 4.91 kg CO_2 eq, respectively.

Ozone layer depletion (OLD) As well as for S1, Halon 1211 and 1301 are emitted to air (1.80E-07 and 1.46E-07 kg CFC-11 eq, respectively), mostly due to foaming ad transport. Causing the 60% of the overall emissions in this impact category, thermoforming is by far the greatest emitter (2.41E-07 kg CFC-11 eq). Substrate production as well, in particular peat, can be considered as an important contributor (9.5%), emitting 6.39E-08 kg CFC-11 eq, followed by final disposal (2.08E-08 kg CFC-11 eq).

Human toxicity (HT) Again, toxic chemical elements such as vanadium, selenium, and barium are emitted to water (1.80E+00, 1.08E+00, and 8.74E-01 kq 1.4-DB eq, respectively), mostly due to plastic production and final disposal. Two categories alone, disposal and forming, together reach the 82.2% of the total emission in this impact category (47.5% and 34.7%, respectively): thermoforming alone emits 2.46E+00 kg 1.4-DB eq (33.1%). Also, it is worth mentioning the pet production, which causes the 9.5% of the total emissions (7.05E-01 kg 1.4-DB eq).

Fresh water aquatic ecotoxicity (FE) Vanadium, copper, and nickel (5.12E+00, 2.49E+00, and 1.77E+00 kg 1.4-DB eq, respectively) are emitted to water, most of which are from final disposal. Seventy-six percent of the emissions in this category are from final disposal, followed by thermoforming (17%) which emits 2.14E+00 kg 1.4-DB eq.

Marine aquatic ecotoxicity (ME) Beryllium and vanadium are emitted to water, most of which are from plastic production and disposal (5.05E+03 and 4.89E+03 kg 1.4-DB eq, respectively). As well as for the abovementioned impact categories, plastic disposal is the greatest emitter (59.8%). Again, it is worth to mention thermoforming and peat production which emit 4.39E+03 and 1.28E+03 kg 1.4-DB eq, respectively.

Terrestrial ecotoxicity (TE) Vanadium to air (8.69E-03 kg 1.4-DB eq), chromium VI to soil (8.72E-03 kg 1.4-DB eq), and mercury to water (6.3E-03 kg 1.4-DB eq) are emitted in this category. Thermoforming alone emits 2.16E-02 kg 1.4-DB eq which represents the 64.2%, followed by final disposal (15.5%) and peat (10.3%).

Photo oxidation (PO) Sulfur dioxide, pentane, and carbon monoxide are emitted to air: 2.30E-03, 1.45E-03, and 1.26E-03 kg C_2H_4 eq, respectively. One category alone (forming), counts for more than half the total emissions (50.4%) in this category. Foaming and thermoforming emit 1.46E-01 (23.9%) and 8.83E-04 (14.5%)kg C_2H_4 eq, respectively. We also want to stress that almost half the emissions are due to polypropylene production (43.5%), which emits 2.65E-03 C_2H_4 eq.

5 Discussion

For all the impact categories, three inputs can be considered the greatest polluters for both S1 and S1+T1: plastic production, forming, and disposal to landfill. The impact due to fertilizers (production and diffuse emissions), pesticides production, and transportation can be neglected because they never exceed the 5% of the total emissions for every impact category. Although the substrate is the greatest input in terms of weight, its contribution to the environmental impact is not so important. In particular, pumice causes emission rates ranging between 0.1% and 0.2% of the total amount.

For what concerns S1+T1, it is interesting to stress the huge increasing registered in the second year of growing, which reaches values up to 747% (fresh water aquatic ecotoxicity), the greatest part of which is due to a restricted number of inputs, first of all PP: the mulching cloth, the trays, and first of all, the pots, are made of polypropylene. As reported in the inventory section, the amount of PP rises from 0.49 to 6.3 kg, most of which are due to the pots adopted over the second year of growing.

This increasing in terms of mass also influences the emissions due to production, forming, and final disposal. For four out of ten impact categories, PP caused the greatest impact; therefore, interventions in this phase of the production system could be useful to reduce the overall environmental impact (e.g., pots and trays made of recycled plastic). Literature suggests both 1- and 2-year-old walnut tree seedlings may be planted to establish a plantation aimed to high-quality timber production, but from the environmental point of view, the differences are important because, as showed in this study, the environmental impact due to S1+T1 is much higher than S1.

Further analysis may be useful for what concerns the recycling opportunity of all plastic inputs that enter the system. Because of lack of data for what concerns the disposal, the worst scenario has been adopted for precautionary reasons; therefore, environmental improving may be expected if recycling is adopted instead of landfill disposal as final scenario; moreover, the environmental impact could be further reduced if recycled plastic (pots, trays, etc.) were adopted. Another important aspects is the transportation of inputs to the nursery (pots, trays, substrate, fertilizers, etc.), which was not considered in our case study because of the lack of data. This aspect would deserve further investigations because transportation is performed by means of fossil fuel-based means of transport (lorry or trucks); therefore, the impact due to fossil fuels production and combustion should be assessed.

6 Conclusions

One- and 2-year-old walnut tree seedlings, aimed to high-quality timber production, were analyzed in this study. The two growing patterns are roughly similar for what concern the quality of inputs that enter the two systems under study. The greatest impact due to 2-year-old seedlings is mostly due to the higher amount of plastic (first of all PP) that enter the system in the form of pots in which the seedling grow over the second year. The impact due to fertilizers and pesticides can be considered as negligible.

Since both 1- and 2-year-old walnut tree seedlings can be planted to establish a walnut tree plantation aimed to high-quality timber production, further investigations regarding the mortality rate of 1- and 2-year-old seedlings after they are planted, are needed in order to compare practical, economic, and environmental aspects.

It is worth to mention that energetic consumptions (and the relative environmental impact) can be considered as negligible. Neither electricity nor other energetic sources are strictly necessary for walnut tree production in our case study, but it may occur for other forestry species, for instance, greenhouse heating (Aldentun 2002). Although greenhouses are not necessary for walnut tree production in Italy, energetic sources might be needed for other purposes (e.g., irrigation): from this point of view, our case study can be considered as an exception since the water is spread, thanks to gravity. Further studies from the energetic point of view are recommended.

Acknowledgments D. Cambria would like to express his gratitude to the University of Basilicata, Department of Crop Systems, Forestry and Environmental Sciences for financing his PhD scholarship. The authors would like to thank the research group at the University of Santiago de Compostela for providing practical support and CODRA® MEDITERRANEA nursery for providing the data.

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